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RUST DISEASES (UREDINALES) ON WHITE SPRUCE (*PICEA GLAUCA* (MOENCH) VOSS) IN INTERIOR ALASKA

(Cooperative Research Report)

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RUST DISEASES (UREDINALES) ON WHITE SPRUCE (PICEA GLAUCA (MOENCH) VOSS) IN INTERIOR ALASKA

I. Introduction

White spruce is the commonest tree species in interior Alaska; it covers approximately 12.8 million acres of land and forms the tallest forest along the large rivers(Hutchinson, 1967). In the past, white spruce was used almost exclusively in the interior for cabins, construction of buildings, bridges, and corduroy roads, etc. Increasingly, white spruce has been sought by the international market; export of Alaska white spruce timber and chips to foreign countries(especially Japan) has increased in recent years, enhacing its economic value.

This summer, large areas near Ruby(north of Yukon river) were found infested with needle rust, at least 60,000 acres. Needle rust epidemic was also reported in Dillingham(south central Alaska). In 1977, cone rust was found to be very common in spruce stands in the Fairbanks vicinity. This fall, an outbreak of white spruce cone rust, covering close to 100,000 acres was observed at Tyonek State Forest. Given the increasing economic value of white spruce forests, epidemics of cone and needle rust make more urgent the need to collect further information on rust diseases.

In the 1957 forest diseases survey of Alaska, Kimmey and Stevenson reported that cone, needle and witches' broom were the rust diseases found on white spruce. Recent evidence shows that their listing was by no means complete. A rust that attacks only the current year's leaf(needle) bud

rust on black and white spruce in the Fairbanks vicinity in 1977. Since this differs from other white spruce rusts both in symptom display and spore morphology, the name "bud rust" was designated.

Another needle rust disease on white spruce was discovered in Tyonek State Forest in 1978. Scanning and light microscopic studies showed that the aeciospores of this needle rust were smaller than on the samples collected around Fairbanks and the ornamentation on the surface of the spore was also different. Since the symptom displays of the two rusts were very similar, location of the sampling was added to the disease name in order to show distinction.

The following report presents the current understanding of witches' broom, bud, cone, fairbanks and tyonek needle rust diseases on white spruce and on their alternate host based on field observations, light and electron microscopic studies. Rust diseases found on vegetation other than white and black spruces in interior Alaska which might be of interest in the future are also listed. Also included is a short description of a recently discovered disease on white spruce causing a type of witches' broom, called "green" witches' broom which is quite different from that caused by rust.

II. Stages and morphology of spruce rust spores

White spruce rusts are heteroecious; in order to complete their life cycle, an alternate host (unrelated to white spruce) is needed. Spermogonia (pyconia) and aecia are the two stages occuring on spruce trees. In witches' broom, bud, fairbanks and tyonek needle rust infested trees, these stages appear on the needles. However, in cone rust, both stages appear on the dorsal (under) side of the scales of the infested cones.

Bearberry (Arctostaphylos uva-ursi), labrador-tea (Ledum decumbens, L. grenlandecum) and winter-green (Pyrola secunda, P. grandiflora) are the

[illegible] alternate hosts of spruce witches' broom (*Chrysomyxa arctostaphyli*), needle (fairbanks) (*C. ledicola*) and cone rust (*C. pirolata*) respectively, and are commonly found on the forest floor in the interior. Telia and uredinia are found on these hosts. On labrador-tea, both telia and uredinia appear on the upper surface of the infested leaves; they were found only on the lower surface of the leaves of winter-green and bearberry. Uredinia succeeded telia on labrador-tea and winter-green. On bearberry, telia was the only spore stage ever found.

A) Spermogonia stage

i) Spermogonia

The spermogonia of spruce rusts were all light yellow in color. Due to the differences in growth pattern, shape and position on infested spruce trees, they can be categorized into three groups: I) witches' broom, fairbanks and tyonek needle rusts, II) bud rust and III) cone rust.

Group I

The spermogonia of this group were globoid in shape. They were found only in the stomata region of the infested needle. The orifices of these spermogonia coincided with the stomata openings(Fig. 1) and the spermogonia of the three rusts were all subepidermal. In the early stages of development, hypha aggregated at the stomata anti-chamber and formed spermogonia primoidium. As the spermogonia primoidium gradually enlarged and differentiated into hymenium and vegetative plectenchyma, the host stomatal and subsidiary cells were gradually stretched and pushed outward into a thin. membrane-like structure.

Group II

Spermogonia of the bud rust were found only at the tip region of the infested needle(Fig. 2). Unlike group I, these spermogonia were intra-epidermal; spermogonia primoidium formed in the epidermal intracellular space beneath the wax layer (cuticle) (Fig. 3). As the spermogonia development progressed, host

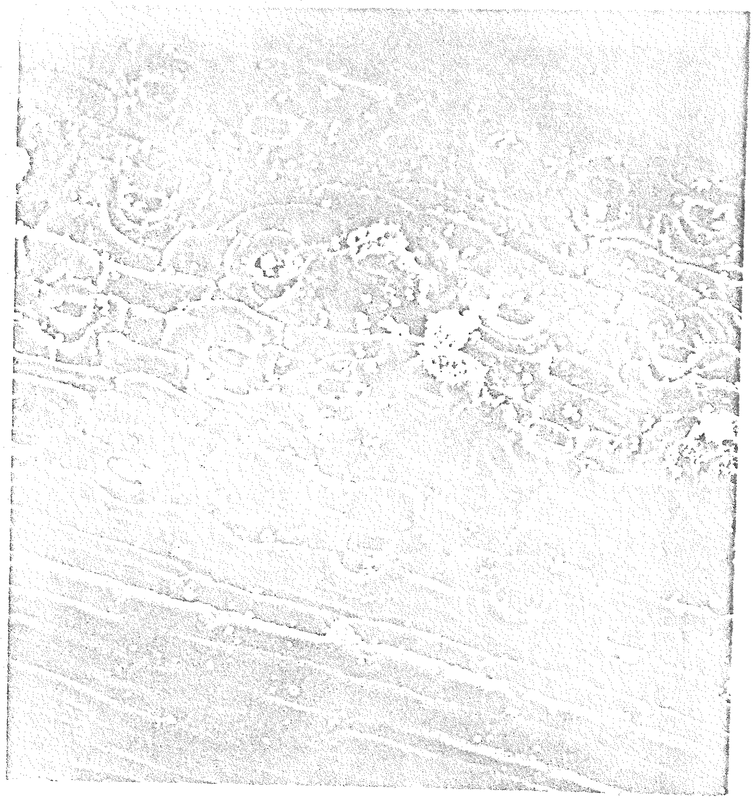

Fig. 1, Spruce witches' broom rust(critical point dried); The sporulating spermogonia in the stomata region of the infested needle. (180X)

Fig. 2, The tip region of a bud rust infested needle. Note the many spermogonia at different degrees of emergence. (critical point dried) (120X)

...mal cells were pushed aside, but the cuticle continued to expand with the spermogonia. Later, a slit developed stretching into a pore-like structure over the orifice of the flask-shaped spermogonia(Fig. 4).

Group III

The shape of cone rust spermogonia was not as well defined as the groups above. Spermogonia primoidium formed in the intracellular space of the epidermis(along the long axis) at the dorsal side of the infested cone scale. Upon maturation, the exposed spermogonia had a somewhat oblong or spindle morphology.

ii) Spermatia

Small spermatia(pycniospores) were produced from the sporophores in the hymenium of the spermogonia. There was very little species distinction in size, shape and coloration of spermatia among spruce rusts. All were from hyaline to slightly yellow in color. Their shapes varied from oval, or ovate to ellipsoid, and their sizes ranged from 1.6 to 2.0u in width and 2.0 to 3.8u in length(Fig. 4, 5). The nucleus was the most prominent feature in the spermatia which occupied most of the cèllular space. The protoplasmic content was very scanty.

Sporophores were all singular, without branch. Spermatia were produced at the tappered tips of the sporophore as buds. When they matured, spermatia became detached from the sporophores through a process of constriction(fig. 3). The spermatia which were released were accumulated above the hymenium and were embedded in a mucilage with a strong sweet odor. In cone rust this gelatinous mixture covered the surface of the infested cone and gave the cone a diagnostic "wet" look. In bud, witches' broom, fairbanks and tyonek needle rust, the spermatia were exuded through the orifice, forming a honeydew.

B) Aecia stage

The aecia stage succeeded the spermogonia stage. Aecia primordium were

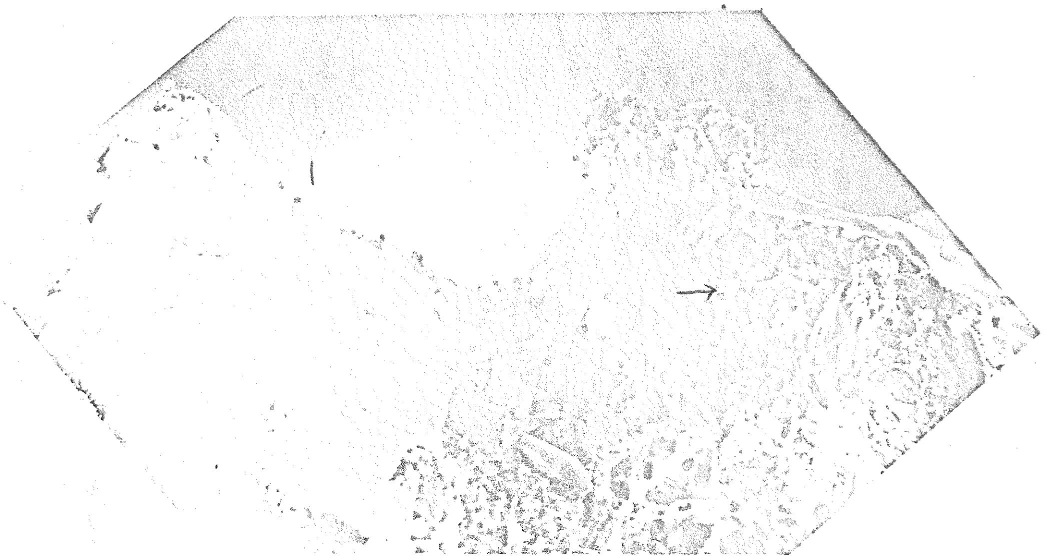

Fig. 3, Spermogonia of bud rust, critical point dried. Note the wax overlay on the spermogonia and the budding spermatia(white arrow). (480X)

Fig. 4, A emerging bud rust spermogonia, critical point dried. (980X)

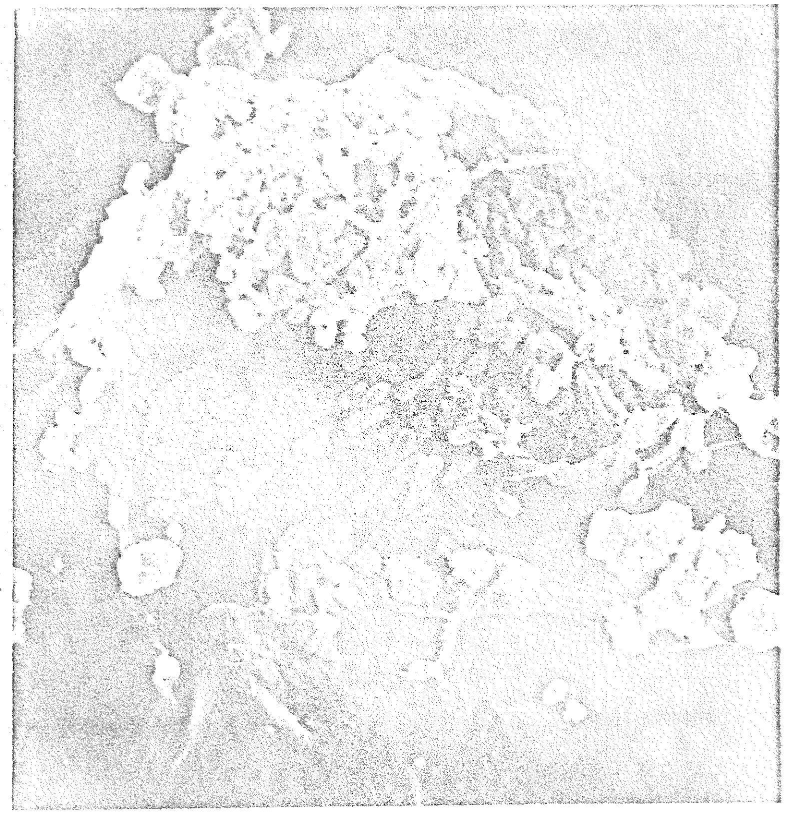

Fig. 5, Spermatia of fairbanks needle rust. Critical point dried. (1560X)

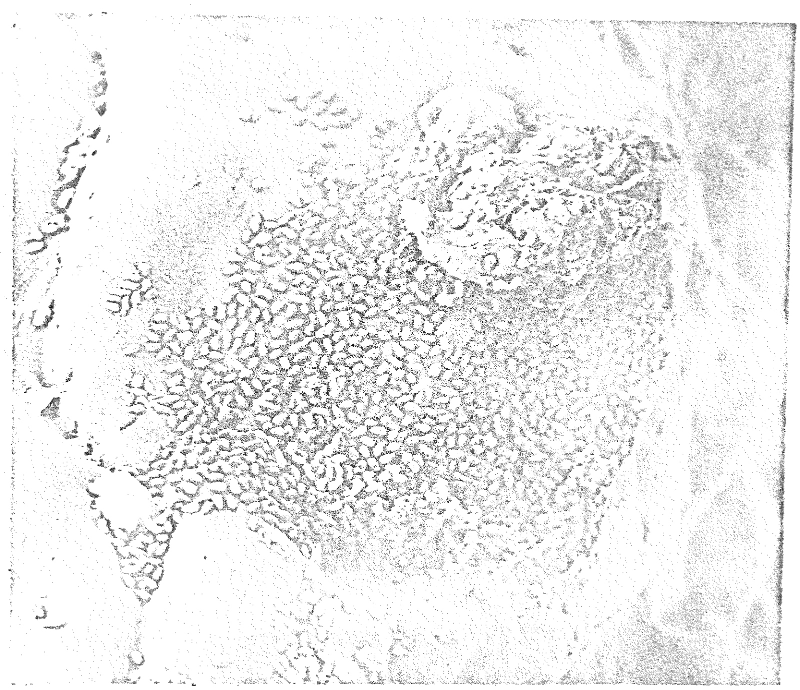

Fig. 6, Spermatia of bud rust. Critical point dried. (310X)

formed in the mesophyll several cell layers beneath the epidermis and were parallel to the long axis of the needle. Host cells were pushed aside and aeciosori emerged from host tissue through a slit. Except for cone rust, aeciosori were all oblong in shape; their length ranged from 1 to 2 mm in witches' broom, from 1 to 3 mm in tyonek needle rust and from 2 to 5 mm in fairbanks needle rust. In bud rust, aeciosori covered the entire length of the stunted needle except the tip region where the spermogonia were located.

The aeciosori of cone rust were blister-like in form. Hymenium formed under a layer of corticular paranchyma which later became partially detached, exposing the aeciospores.

i) Peridia

The aecia were surrounded by white-colored peridia. In witches' broom, bud, and needle rusts, the peridia were joined together, forming a membrane with a single layer of cells. The peridia in cone rust were a loosely packed layer of cells overlayying the aeciospores. They adhered to the host corticular epidermis, later becoming detached from the sori. Peridia in the aecia stage were all spongy in texture with deep cleavages. The cleavages and some other features of the peridia bore species distinction.

In witches' broom rust, the cleavages seen at the inner surface(facing the center of the sori) were quite fine. The outer surface of the peridial membrane was smooth. Peridia were flattened in the center area with a ridge around the periphery consisting of scanty protoplasmic content, the nucleus and the wall(Fig. 7). They were mostly pentagonal and hexagonal in shape and overlapping slightly when forming the membrane.

The outer surface of the peridia in tyonek needle rust was also smooth (Fig. 8). But the cleavages at the inner surface were very coarse(Fig. 9).

Fig. 7, Peridial membrane of white spruce witches' broom and a aeciospore. Note the nucleus at the corner of peridium. Air dried. (1440X)

Fig. 8, Aeciospores and peridia of tyonek needle rust. Air dried. (930X)

Peridia were flattened in the center with a high ridge formed around the peripheral; no nuclei were observed. Besides pentagonal and hexagonal, spindle-shaped peridia were also common.

In fairbanks needle rust, the cleavages seen at the inner surface were very fine(Fig. 10). Delicate networks were observed on the outer surface of the peridia(Fig. 11). The peridia were also flattened in the center region with ridges around the periphery; no nucleus was visible. The most common shapes in peridia of this rust were pentagonal and hexagonal.

Unlike other rusts descirbed above, the peridia of bud rust did not show differences in height between the center area and the periphery. The outer surface was covered by a very coarse network. The cleavages seen at the inner surface were fairly fine. Pentagonal and hexagonal shaped peridia were most common.

In cone rust, peridia did not join together to form membrane-like structures. The spherical to oblong shaped peridia with the deep cleavages closely resembled powder puffs(Fig. 12). Peridia in cone rust were much larger than the aeciospores; their size ranged from 27.0 to 40u in width to 40 to 50u in length.

ii) aeciospores

In spruce rust, aeciospores bore the strongest species characteristics; they differed in size, shape, color and in spore surface ornamentation. Characteristics of spores of the five spruce rusts are described as follows;

<u>Witches' broom rust</u>

The aeciospores of witches' broom rust were bright orange in color; their size ranged from 12.5 to 24.0 u in width and from 22.5 to 34.0 u in length (Fig. 13). Long(2.5u), annulated cylindrical appendages(Fig. 14, 15) covered the surface of the spore. A band with a rough surface, characteristic of this

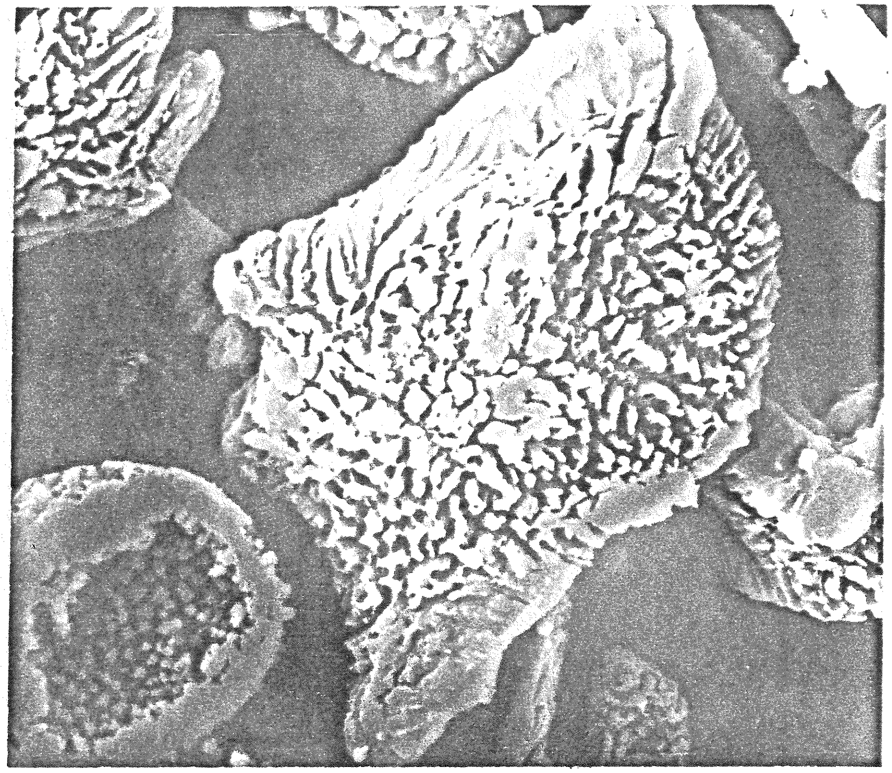

Fig. 9, Inner surface of the peridium of tyonek needle rust. Air dried. (2640X)

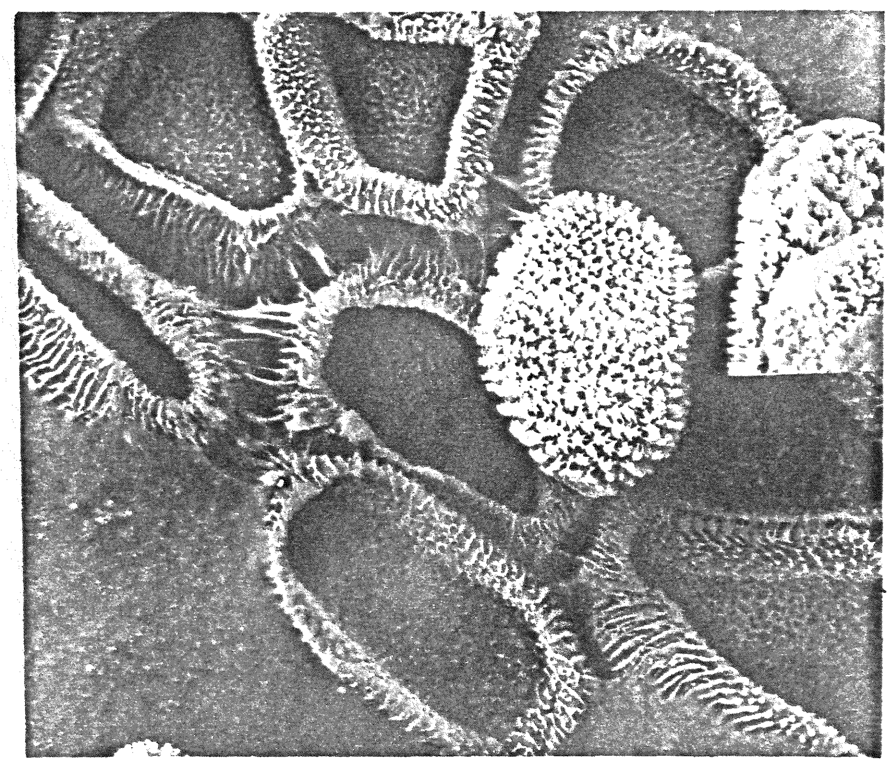

Fig. 10, Aeciospore and peridia. Note the fine network on the outer surface of the peridia. Air dried. (1320X)

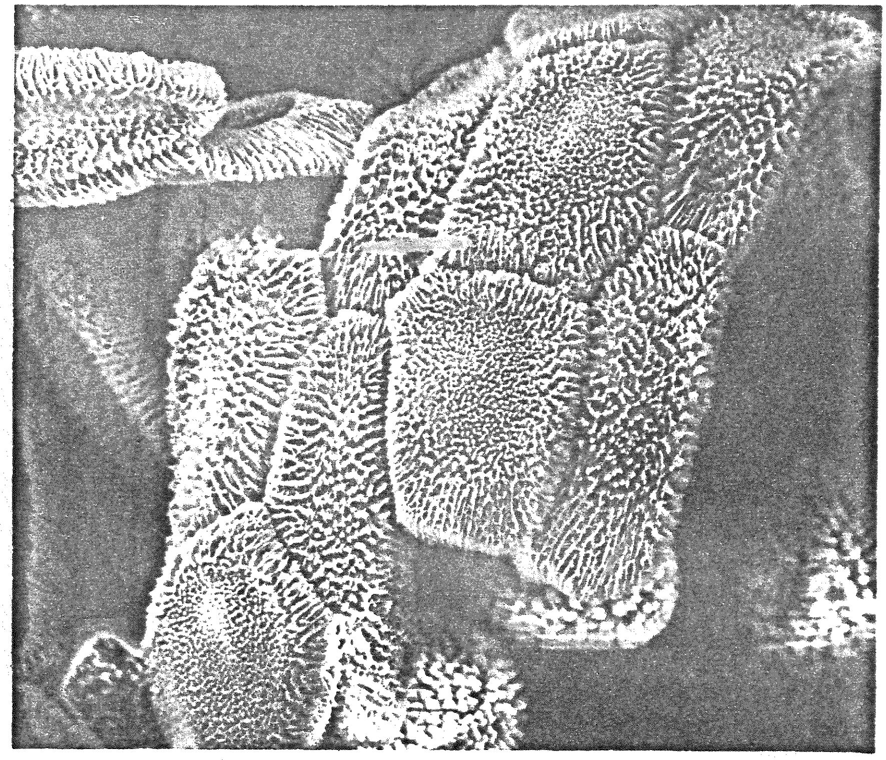

Fig. 11, Inner surface of peridial membrane. Air dried. (1130X)

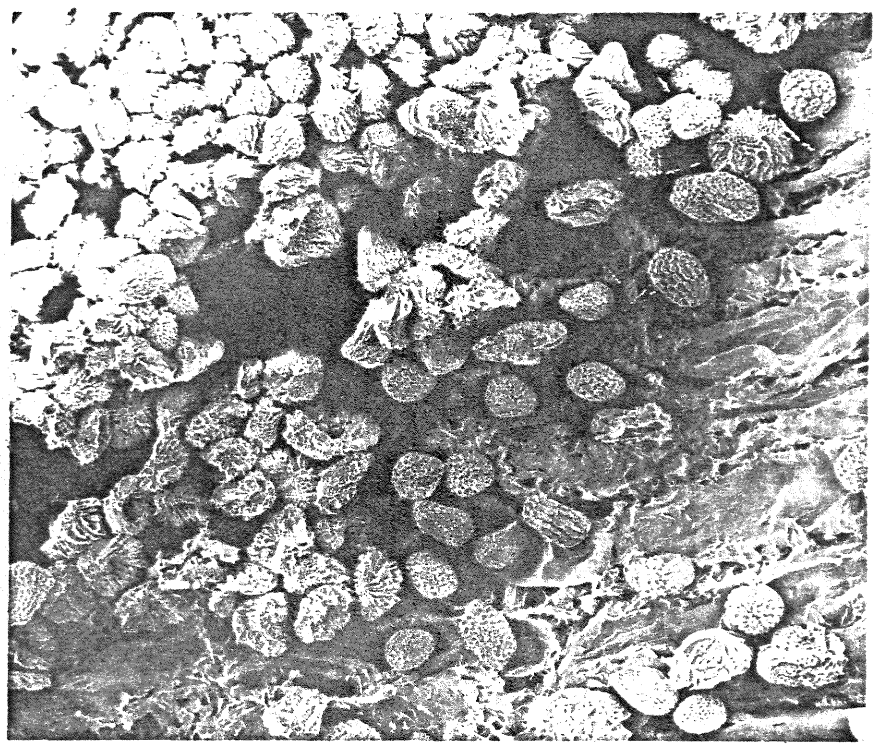

Fig. 12, Cone rust, aeciospores and large spongy peridial on the detached cortical parenchyma. Air dried. (260X)

Fig. 13, White spruce witches' broom rust. The aeciospores. Air dried. (1800X)

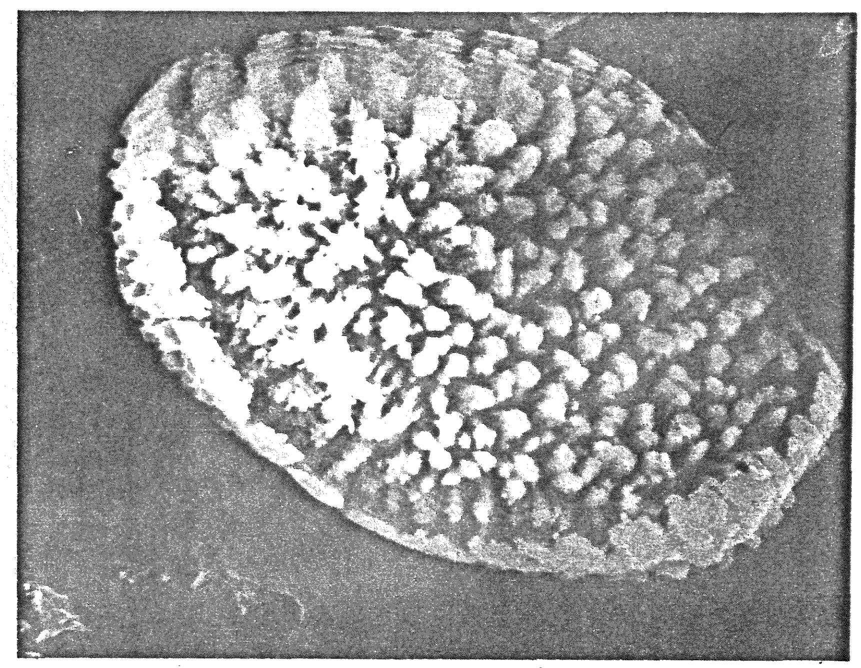

Fig. 14, Aeciospore of white spruce witches' broom. Air dried sample. (3840X)

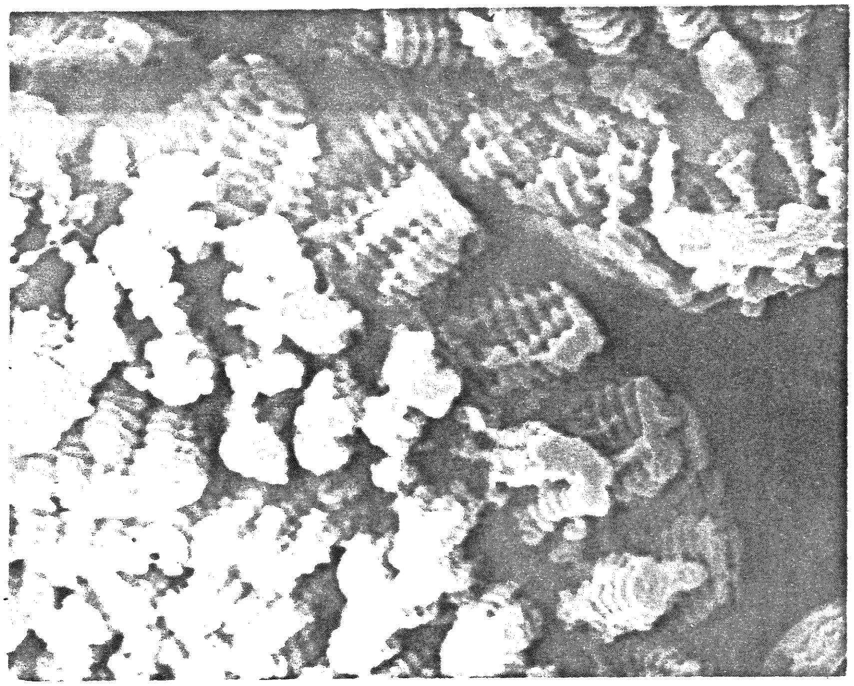

Fig. 15, A close up of the appendages of aeciospore of spruce witches' broom rust. Air dried sample. (8640X)

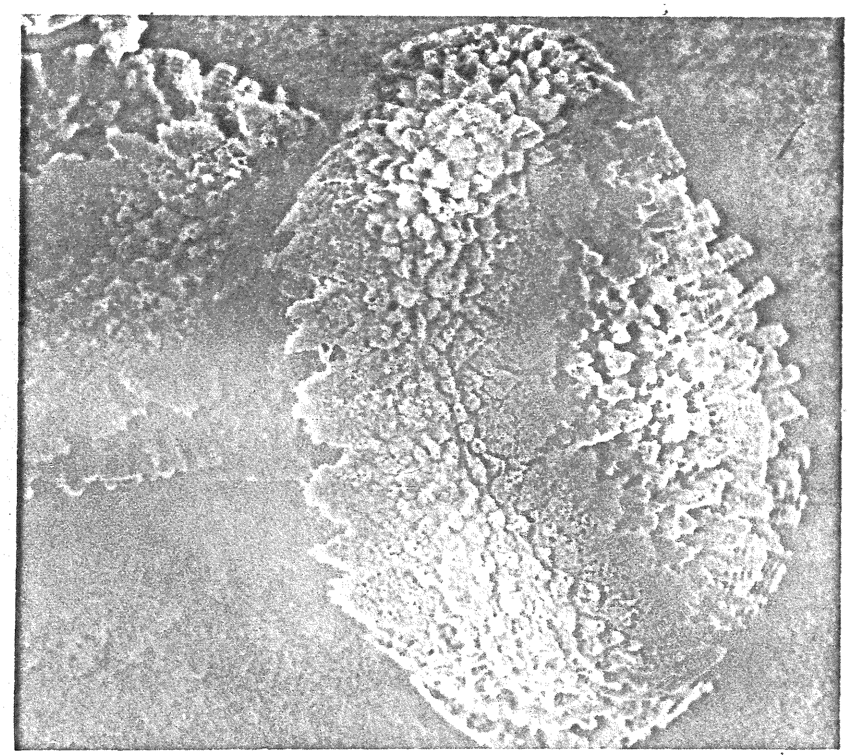

Fig. 16, Aeciospores of spruce witches' broom rust. Note the rough surfaced band. Air dried. (3120X)

rust, was observed(Fig. 16). Many of the air-dried aeciospores were concave in shape, similar to a watchglass with the band appearing to serve as the spine(Fig. 14). No differences were found between the aeciospores on black and white spruce.

<u>Fairbanks needle rust</u>

The aeciospores were reddish-orange in color; their size ranged from between 17.5 and 27.5 μ in width to between 22.5 and 32.5 μ in length(Fig. 17). The annulated appendages of the aeciospores of needle rust were conical in shape; they were approx. 1.7 μ in height(Fig. 18, 19). A band with a smooth surface consisting of partially cleaved aggendages was also characteristic of this rust(Fig. 20).

<u>Tyonek needle rust</u>

The aeciospores of this rust were orange in color; their size ranged from 11.5 to 22.5 μ in width and 14.5 to 25.0 μ in length(Fig. 21). The annulated appendages on the surface of the aeciospores were also conical in shape but much shorter(0.5 to 1.0 μ)in height and sparsely distributed. Holes and depressions were observed frequently on the surface of the spores (Fig. 22). It is unclear whether this is an indication of defect. Large smooth bands and patches were also observed. Some of the bands also served as spine for the spores as in witches' broom rust(Fig. 8).

<u>Bud rust</u>

The aeciospores of bud rust were bright yellow in color; their size ranged from between 10.9 and 25.0μ in width and 23.4 and 34.4 μ in length. Long (approx. 1.0 to 2.0μ in height) annulated appendages covered the surface of the aeciospores. The shape of these appendages was generally cylindrical. Occasionally, partially cleaved appendages were seen as small patches, but no band or smooth area was ever observed(Fig. 23).

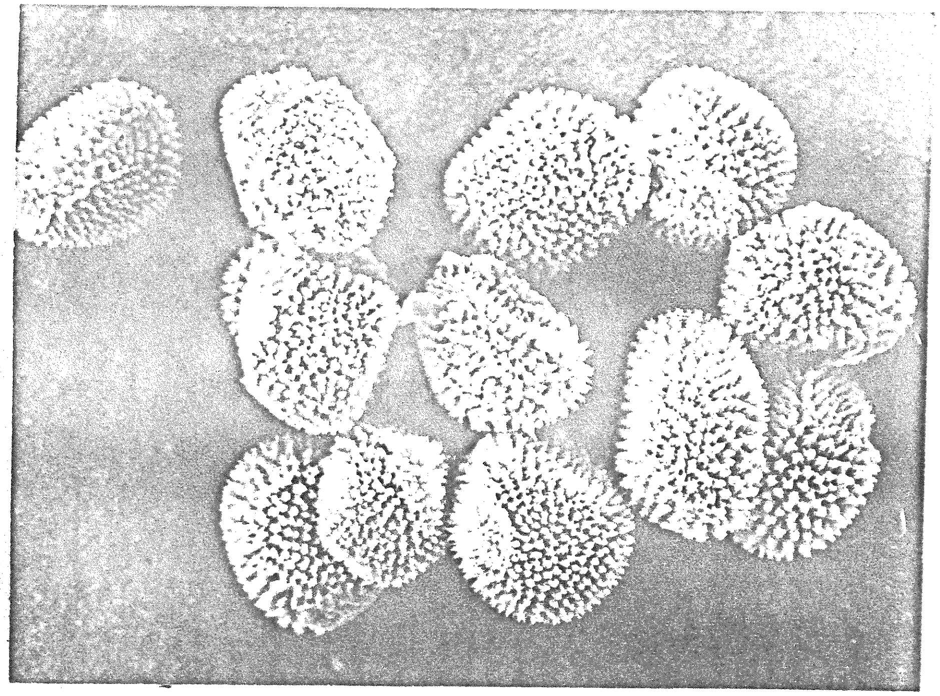

Fig. 17, Aeciospores of fairbanks needle rust. Air dried sample. (1030X)

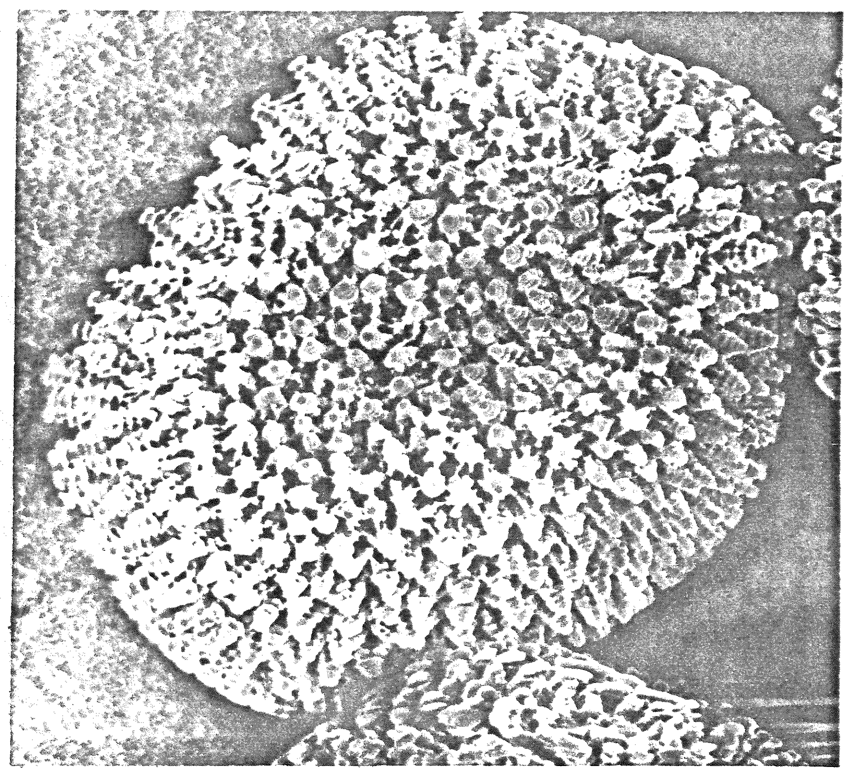

Fig. 18, An aeciospore of fairbank needle rust. Air dried sample. (3120X)

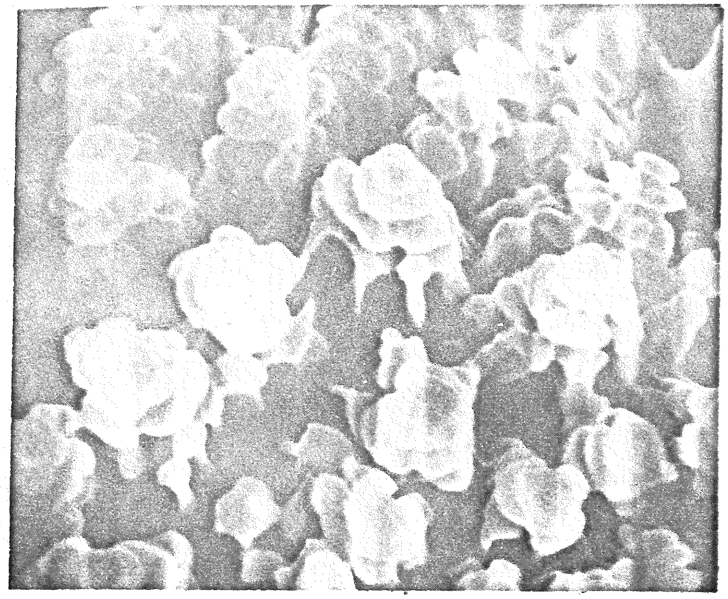

Fig. 19, A close-up of the appendages of a fairbanks needle rust aeciospore. Air dried sample. (10,320X)

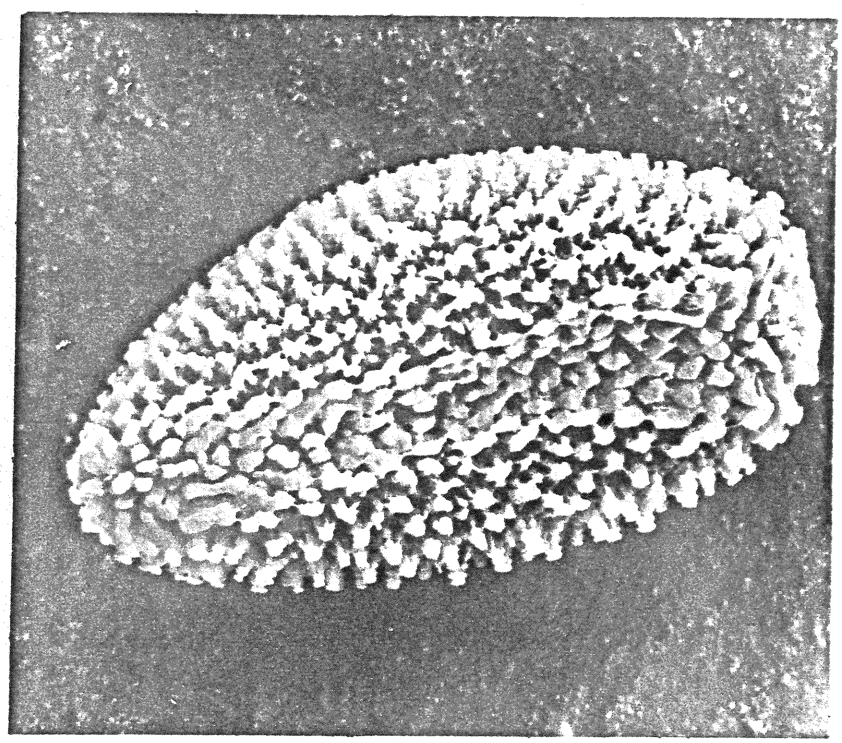

Fig. 20, Aeciospore, fairbanks needle rust. Note the band of partially cleaved appendages. Air dried sample. (2880X)

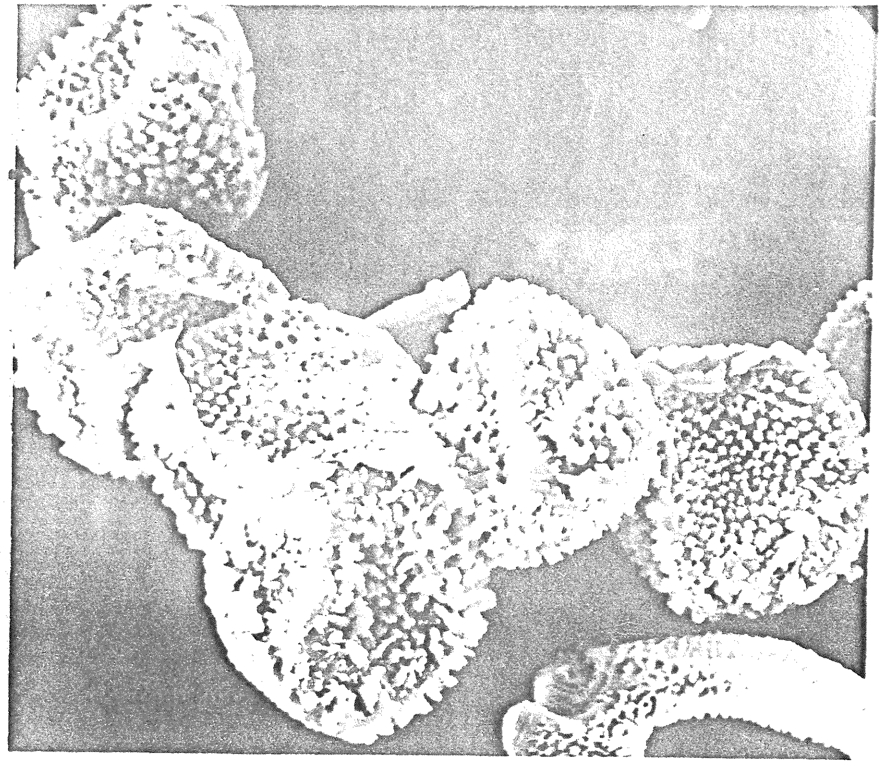

Fig. 21, Aeciospores. Tyonek needle rust. Air dried sample. (1320X)

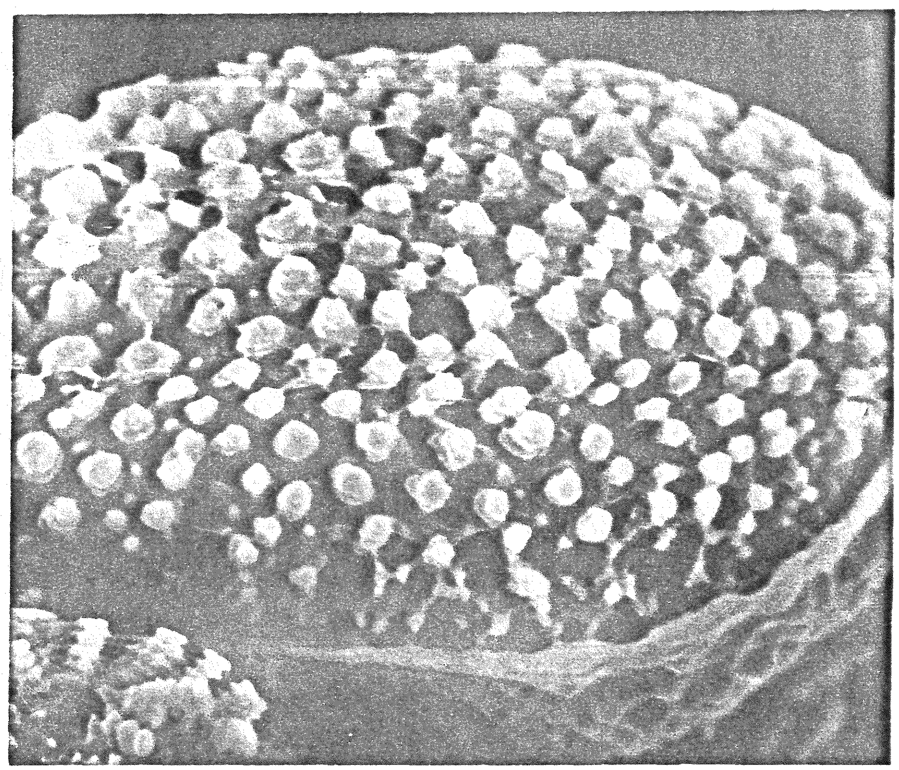

Fig. 22, Tyonek needle rust aeciospore, a close-up. Air dried sample. (7200X)

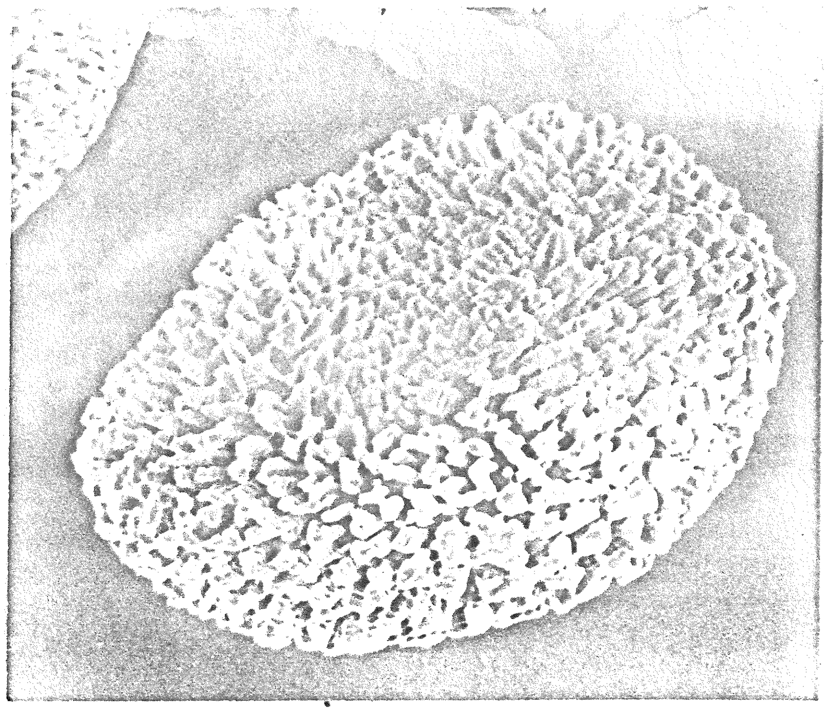

Fig. 23, Aeciospore of bud rust. Air dried sample. (3600X)

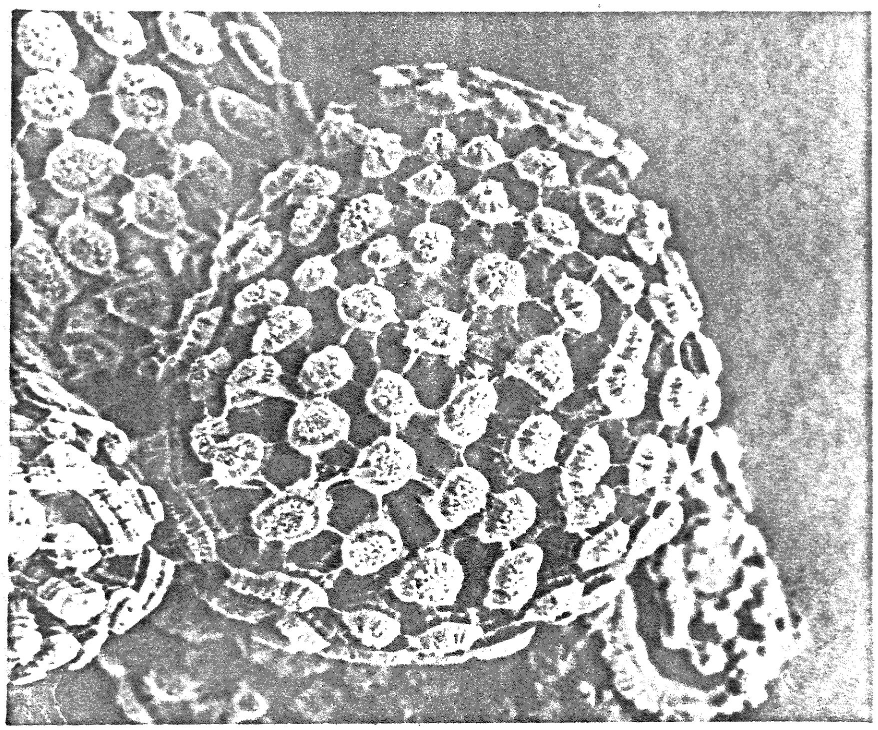

Fig. 24, Cone rust aeciospores. Air dried sample. (3120X)

Cone rust

The aeciospores of cone rust were bright yellow in color; their size ranged from between 17.0 and 21.5 μ in width to between 21.3 and 33.5 μ in length. The surface of the aeciospores was covered by large annulated columnar appendages; they were approx. 1.2 to 2.6 μ in width and 3.1 to 4.0 μ in length and 3.0μ in height. These appendages were frequently connected by a thin, delicate bridge, forming an intricate lattice pattern(Fig. 24). Although merging of two or three appendages was common, no band was ever seen. These appendages were appanrantly hollow in the center(Fig. 25). Holes were also observed in the broken appendages which might led to the interior of the spore(Fig. 26).

A peculiar sturcture was observed on the aeciospores of cone rust under the scanning electron microscope. This structure, approx. 4.1 to 6.8 μ in diameter, was located mainly at the polar region of the spore. The center area was either a round depression(Fig. 27) or a plug-like protrusion(Fig. 28) surrounded by a circular or two semi-circular appendages without annulation. The function of this structure is still undetermined.

C) Telio stage

Telia on bearberry, labrador-tea and winter-green were all sub-epidermal. Light orange colored telia primoidium formed in the mesophyll; they were found in the palisade tissue on labrador-tea and in the spongy tissue on bearberry and winter-green. The host tissue was pushed aside to give way to the telia. The matured teliosori covered with host cuticle protruded slightly above the epidermis. They were orange in color with a waxy shine. The shape of these sori was usually round to oblong in bearberry and winter-green but angular in labrador-tea. Teliospores were light orange in color. A strand of 4 or 5 teliospores formed a spore chain. All spore chained were packed tightly together in the sori.

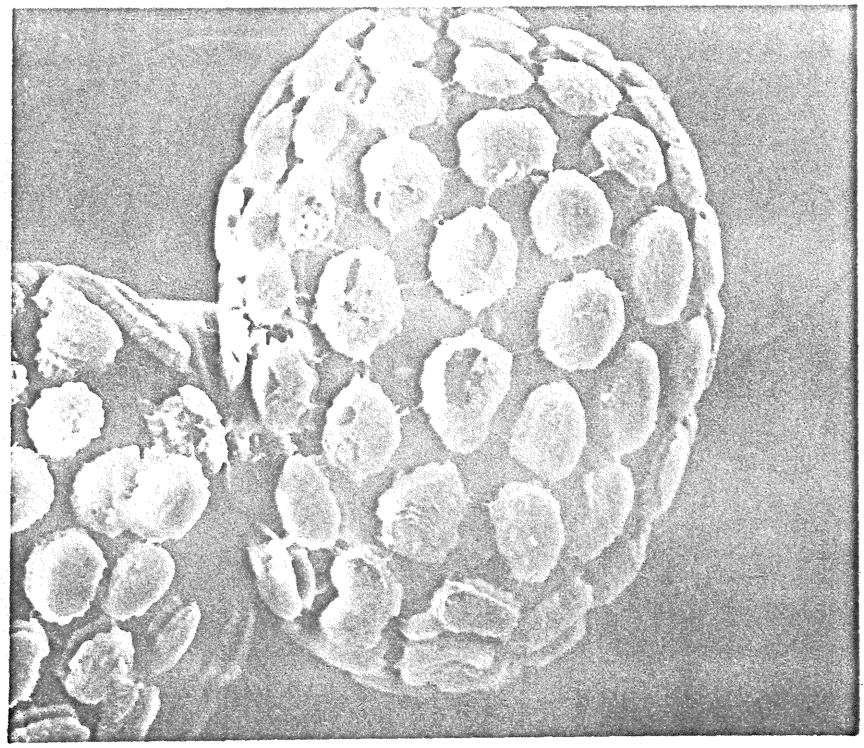

Fig. 25, Cone rust aeciospore with broken appendages. Air dried sample. (3120X)

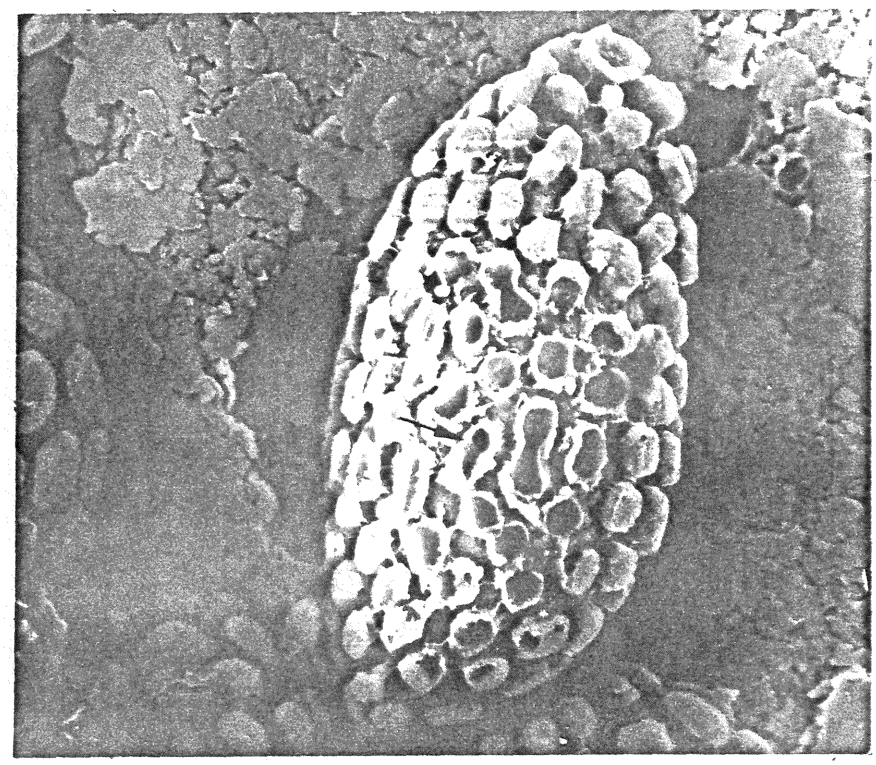

Fig. 26, Cone rust aeciospores with fractured appendages. Note the hole(arrow) at the base. Air dried sample. (2640X)

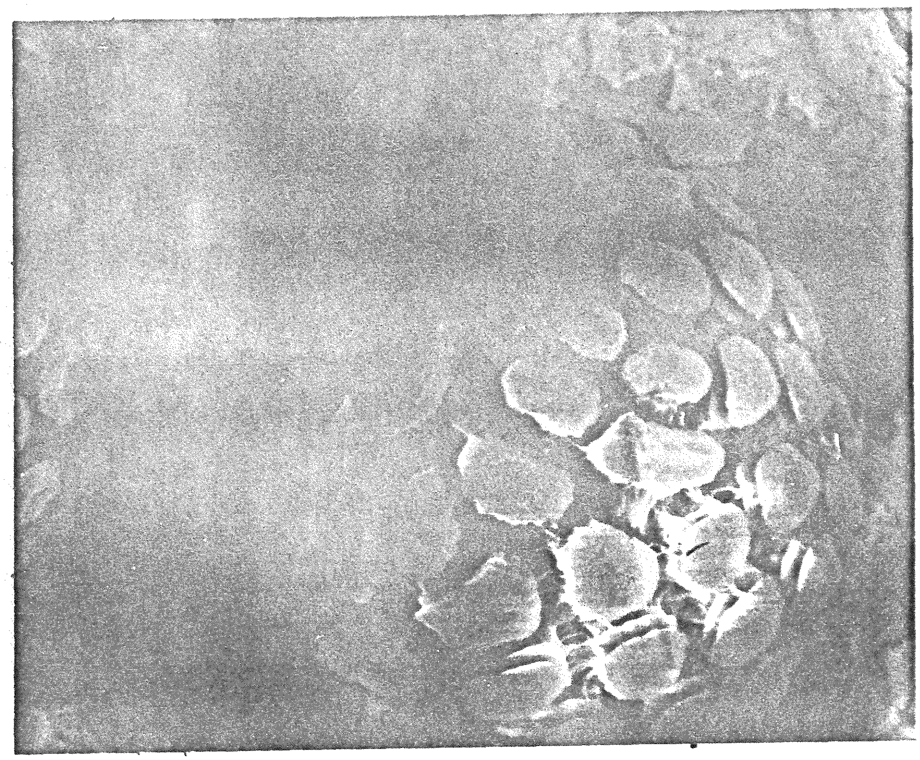

Fig. 27, Cone rust aeciospores. Note the pit-like depression at the polar region. Air dried sample. (3840X)

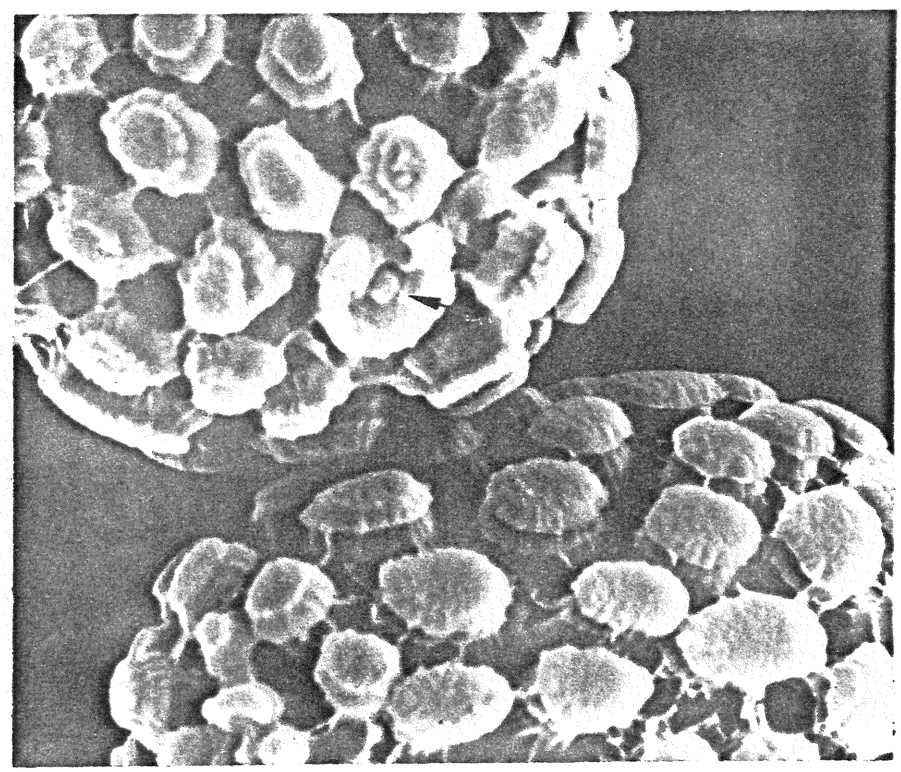

Fig. 28, Cone rust aeciospores. Note the plug-like protrusion(arrow). Air dried sample. (4320X)

Upon germination, telia erupted from the host tissue. In labrador-tea, the overlaying cuticle and epidermis cracked open to expose the teliosori(Fig. 29). But, in bearberry and winter-green, only small cracks were formed as each emerging basidium penetrated through the overlaying tissue (Fig. 30).

The basidium was a short, stubby structure(Fig. 30). It was produced only by the top-most teliospores in a spore chain. On winter-green and bearberry, the basidium production started at the periphery of the teliosori (with direct contact with the host cells) then gradually progressed to the center. The thin-walled basidia curved and intertwined on the surface of the sori, often forming a criss-cross pattern(Fig. 30).

Long, thin sterigma were observed on the basidia on labrador-tea(Fig. 31). Small (approx. 7 u in diameter), thin-walled basidiospores with a smooth surface structure were formed on the tapered tip of the sterigma as buds(Fig. 31). Similar to the production of spermatia, the mature basidiospores were also becoming detached through the constriction process(Fig. 31). Sterigma on bearberry and winter-green were very short which made basidiospores appear as though they rose directly from the basidia.

Humidity apparently plays a very important role in the dissemination of basidiospores on labrador-tea. When the humidity was high, the height and width of the teliosori increased visibly, as if to gain the greatest exposure. As the humidity declined, teliosori also were reduced in size. When the enviromental conditions improved, teliosori increased their sized again. In bearberry and winter-green, this phenomenon was less prominent.

After the dissemination of the basidiospores, the telia stage was gradually taken over by the uredinia stage.

Fig. 29, Half-opened teliosori on labrador-tea. Critical point dried sample. (90X)

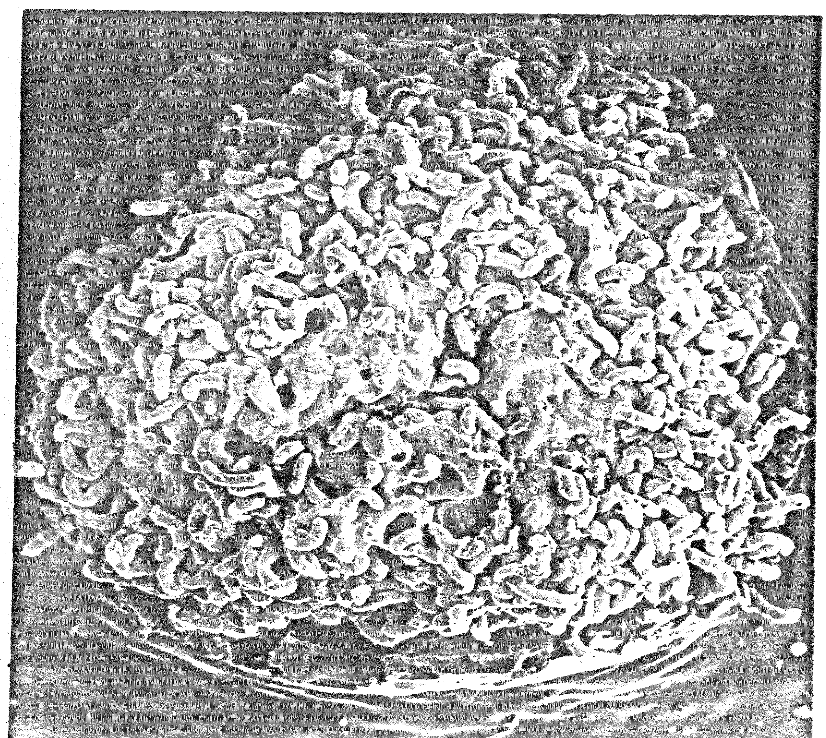

Fig. 30, Teliosori with emerged basidia on winter-green. Critical point dried sample. (310X)

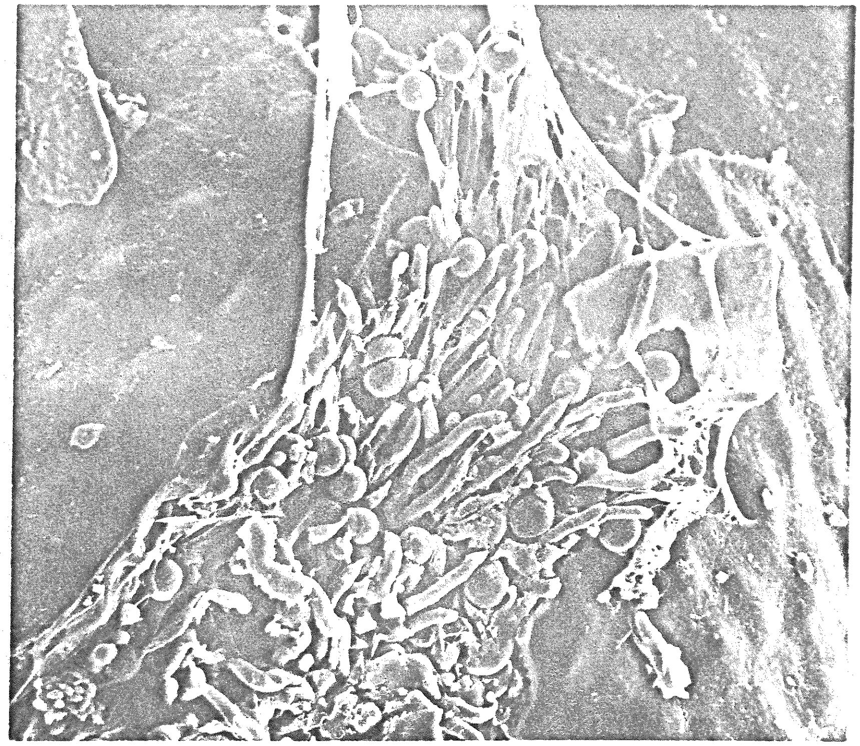

Fig. 31, Basidiospore and sterigma in a half closed teliosori. Critical point dried sample. (720X)

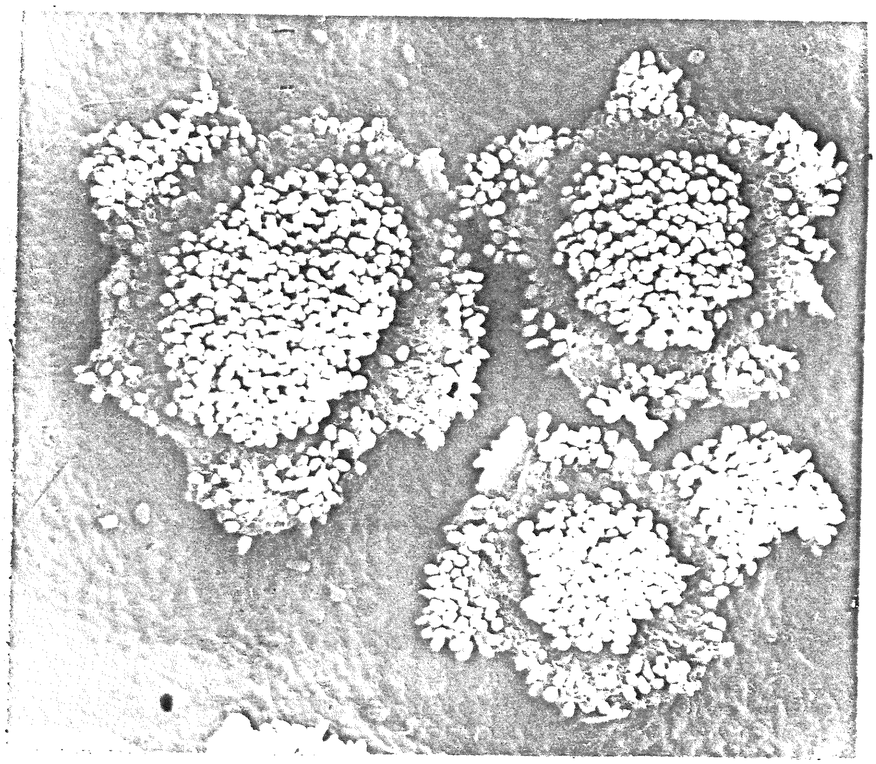

Fig. 32, Cup-shaped uredinia on winter-green. Critical point dried sample. (100X)

D). Uredinia stage

The uredinia stage was observed on labrador-tea and winter-green and on both hosts, the uredinia emerged from the teliosori. No uredinia was ever found on bearberry; telia on this plant turned dark brown and dried in appearance.

i) Peridia

The urediniosori in winter-green were cup-shaped; a large number of powdery, orange-colored urediniospores were surrounded by a prominent white peridial wall(Fig. 32). The peridia were not spongy in texture; the outer surface was quite smooth, and the inner surface was decorated with conical projections. Most peridia were cuboidal in shape with depressions in the center(Fig. 33).

No peridial wall was observed in urediniosori on labrador-tea. The cracked overlaying tissue provided some support when the orange colored urediniospores piled on top of the sori.

ii) Urediniospores

The urediniospores produced on labrador-tea bore a striking resemblence to the aeciospores of spruce needle rust(fairbanks) (Fig. 34). The surface of these spores was also decorated with conical, annulated appendages. A band of smooth area composed of partially cleaved appendages was also seen. The size of these spores ranged from 21.0 to 23.6 μ in width and from 25.4 to 27.2 μ in length.

The resemblence between the urediniospores on winter-green and the aeciospores of spruce cone rust was not so obvious. Although the surface of the urediniospores was also decorated with appendages, it was much shorter (approx. 1 μ in height); the annulations were not so distinctive, and they were conical rather than columnar in shape (Fig. 35). The size of these urediniospores ranged from 13.0 to 16.7 μ in width and 15.5 to 26.6 μ in length.

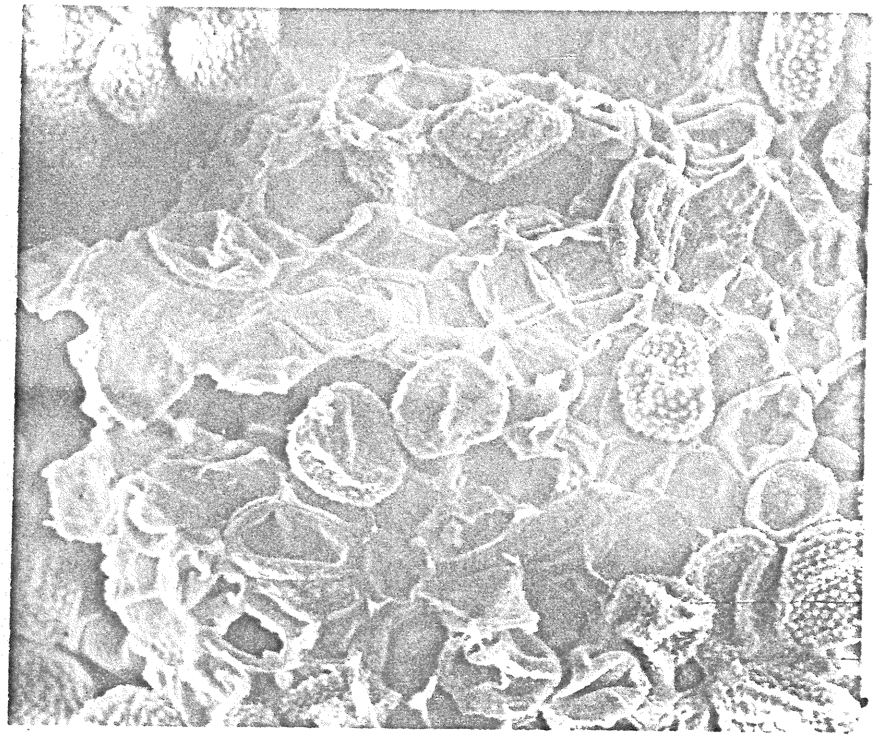

Fig. 33. Peridia of Uredinia on winter-green. Critical point dried sample. (930X)

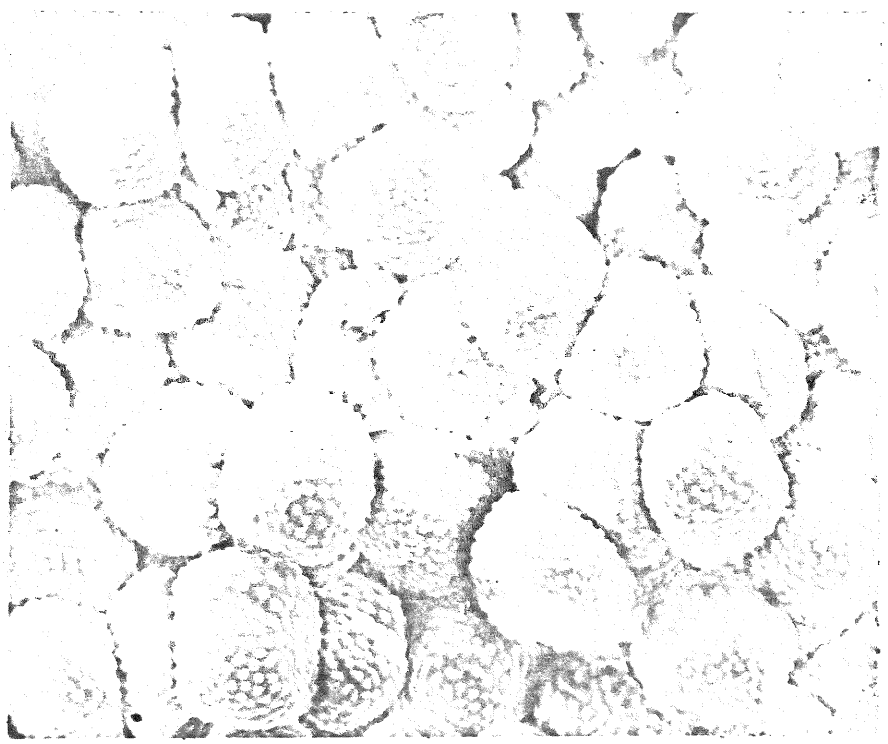

Fig. 34. Urediniospores on winter-green. Critical point dried sample. (1320X)

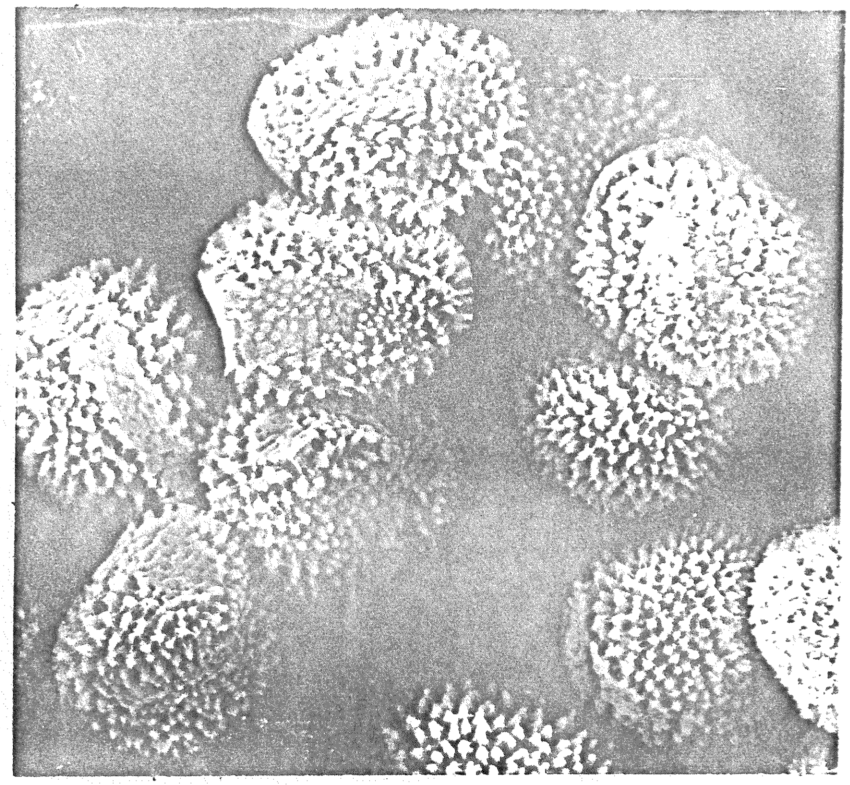

Fig. 35. Urediniospore on labrador-tea. Air dried sample. (1320X)

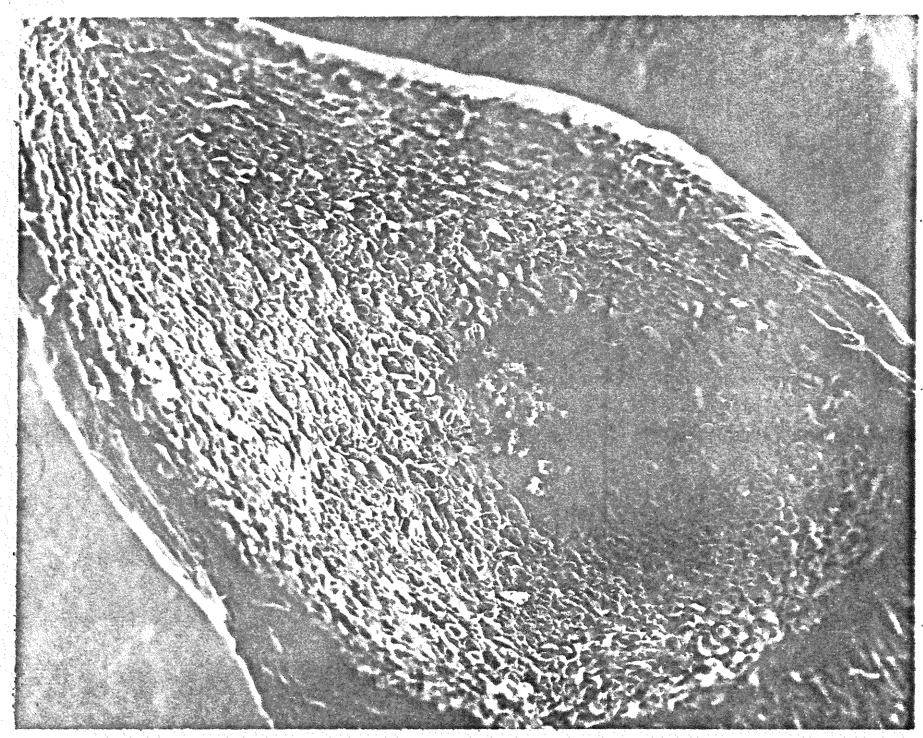

Fig. 36. Healthy white spruce seed. Scale-side up. Air dried. (48X)

III. Symptomatology and infectious cycle of spruce rusts

A) Witches' broom

Witches' broom was found on both black and white spruce trees. So far, no differences have been found in spore morphology and symptom display between black and white spruce witches' broom rusts.

This rust attacks the spruce trees primarily on the trunk, causing an abnormal proliferation of branches. Both internodes and needles on these broomed branches are shorter than normal. From the end of June until early August, the sporulating aeciosori on the needles color the whole broom a striking orange. By the end of August, needles fall from the broomed branches; the broom has a naked, dead-looking appearance and is frequently mistaken for a bird or squirrel's nest.

Witches' broom is the only spruce rust disease known to be able to perpetuate itself on spruce. There is no need to renew infection every year once the broom has established. Histological studies have shown the presence of rust mycelium in the meristemic tissue in the unopened bud on the broomed branches which is one of the indications that this rust over-winters in the mycelium form.

The development of spermogonia is synchronized with the host tissue. In mid-May, the spermogonia appears on the needle as the bud on the broomed branches unfolds, and it starts to sporulate in approx. 14 days. The spermogonia usually remains active for approx. 5 to 7 days and then gradually shrivells into tiny black scars. A period of 14 days passed before the emergence of the peridial wall enclosed aecia from the needle. An additional 7 days passed before the sori reached a sporulating state. Many orange colored aeciospores were produced from these sori. Aeciosori remained active until early August, for a total of 5 weeks. By late August, these needles had shrivelled and fallen from the broomed branches.

event of heavy infection (80-100%), the branch remained bare throughout its life; no bud was ever formed.

On labrador-tea, urediosori emerged from teliosori at the end of June and remained active in sporulation until the end of the August.

C) Cone rust

Cone rust on spruce has been collected from the Fairbanks vicinity, Mt. Mckinley area and Tyonek State Forest. So far, no detectable differences were found either in symptom display or spore morphology among these samples. Nor was any differences found between black and white spruce cone rust.

In early July, wet-looking cones (covered with secretions from the spermogonia) were the first indication of rust infestation. The sign of infection became more obvious in the aecia stage; the cone was covered with powdery bright yellow aeciospores. Aeciospore also filled the space between the scales. The scales of cones opened prematurely and gave the cone an "old" look. When it rained, the infested cone absorbed moisture rapidly and developed a water-soaked appearance which can be recognized readily. Infested cones were also prone to secondary infections.

Aeciosori were located at the dorsal-side of the scale. Rust (mycelium) was also found on the wing and seed coat of the seeds in the infested cone. On the seed coat, rust hypha were restricted to the cone scale, facing the side of the seed(Fig. 37). On the wing-side of the seed, the seed coat remained almost free of mycelium(Fig. 38).

Rust infection on winter-green was perenial (old leaves bearing sori scars were commonly found). In early May, telia were seen as small orange spots on the previous year's leaves; they usually covered the whole lower surface of the leaf. Uredinia emerged from the teliosori and became visible in mid June when massive powdery orange colored spores appeared. These sori remained active in sporulation until fall and died in the winter together

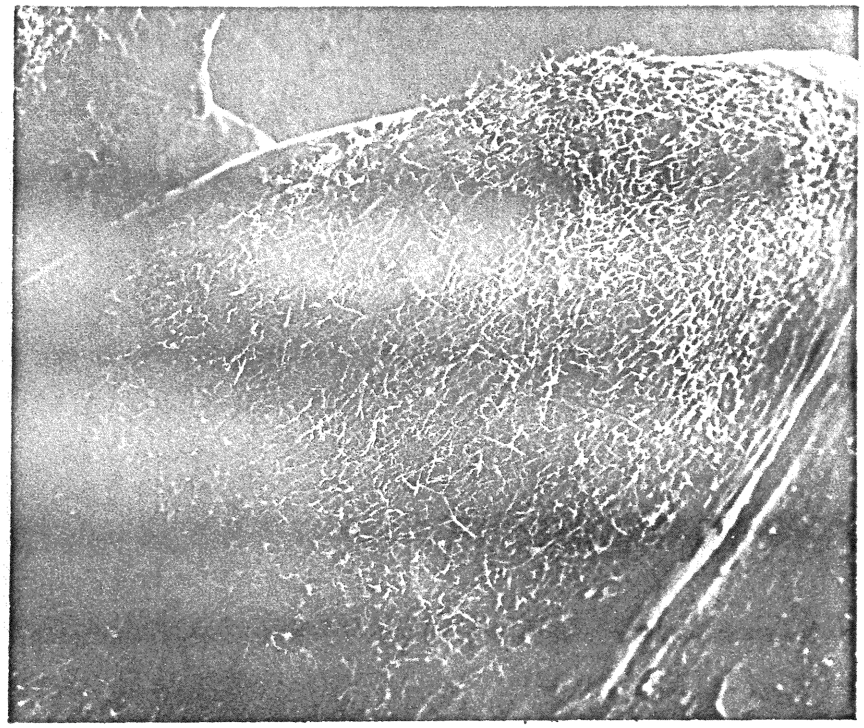

Fig. 37. Seed produced from rust infested cone. Note the mycelia on the seed coat. Air dried. (48X)

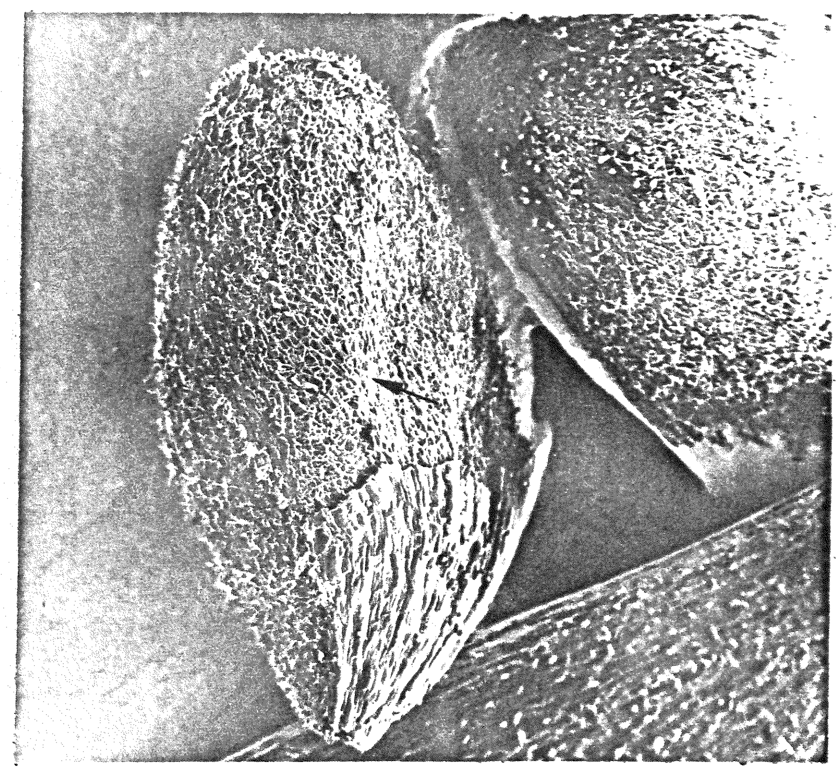

Fig. 38. Seed produced from rust infested cone, wing-side up. Note the absence of mycelium in the area originally covered by the wing. (30X)

with the infested leaves.

The method of dissemination of basidiospores from winter-green to spruce is a puzzle. Winter-green found in a cone rust infested spruce stand was devoid of rust infection; those carrying Chrysomyxa rust symptoms were far distant in either balsam poplar stands or in a spruce stand with no sign of rust infection.

Other problems such as the time of infection and port of entry of the cone rust on spruce also remain unclear.

D) Bud rust

Bud rust was found on both black and white spruce trees. It attacked the terminal buds primarily; but occasionally it infected one or two lateral buds together with the terminal bud. Bud rust infection first became visible in late May when the buds of spruce needles started to unfold. Unlike the normal green young shoots, the infested shoots were bright yellow in color and severely stunted.

Small spermogonia were found exclusively at the tip region of the needles: aecia primoidia, seen as long, yellow streaks beneath the four bands of stomata, gave the needle a distinctive yellow color. By early June, aeciosori emerged from the host tissue. Later, the white peridial wall cracked and released many bright yellow colored aeciospores. The aeciosori remained active until mid July; then the infested needle became dehydrated.

Frequently, one or two of the lateral buds would produce shoots: some were healthy looking but more often they were small and twisted. More than one of these abnormal shoots was often produced by one lateral bud which gave it a small witches' broom appearance. Aecia could also appear on needles of these abnormal shoots that had close contact with the infested bud. However, no spermogonia could be found on these needles. Needles on the abnormal branches fell in the

fall.

The infectious cycle and alternate hosts of this rust are still unknown.

E) Tyonek needle rust

So far, tyonek needle rust has been found only on white spruce trees. Unlike fairbanks needle rust, this rust was found mostly on the top portion of the tree. Its symptom display was very similar to the fairbanks needle rust; small spermogonia and oblong-shaped white peridial clad aeciosori were found at the stomata region of the infested needles. Aeciospores of this rust were orange in color.

The alternate host(s) and infectious cycle of tyonek needle rust are also unknown.

IV. White spruce green witches' broom disease

Green witches' broom on white spruve was first discovered in the Bonanza Creek Experimental Forest. Later, more of this kind of broom was also found on white spruce trees along the Tanana river bank. Thus far, all the green witches' broom found have been on the upper portion of the tree. This broom also appeared to be perennial; new shoots sprouted yearly from the broomed branches. The size of these brooms varied greatly, from 14 or 15 inches to 5 or 6 feet in diameter.

The unfolding of needle buds on the broomed branches in the spring was slower than normal. The internodes on these brooms were very short and extremely profuse which gave the broom a tightly knit appearance. Needles on these branches were short, stubby and slightly dark green in color. Unlike the rust witches' broom, the green witches' broom retains all its needles and stays green in color all year long. No rust was ever found on the green witches' broom. The cause of this abnormality is still unknown.

V. Other rust diseases found in interior Alaska

In addition to spruce rusts, many other rust diseases were also found on vegetation in interior Alaska. Based on their taxonomy, host, spore stages observed and their location on the host, these rust diseases can be catagorized as follows:

Rust Species	Host	Spore Stages	Location on host
Chrysomyxa sp.	labrador-tea (*Ledum spp*)	uredinia	lower epidermis
Melampsora sp.	aspen (*Populus tremuloides*)	uredinia, telia	lower epidermis
"	willow (*Salix spp.*)	uredinia, telia	upper and lower epidermis, petiole, flower parts
Puccinia sp.	bed straw (*Galium trifidium*)	telia	lower epidermis, bracts
"	dandelion (*Taraxacum spp.*)	uredinia, telia	upper & lower epidermis
"	alaskan rhubard (*Polygonum alaskanum*)	telia	lower epidermis
"	fireweed (*Epilobium sp.*)	telia	lower epidermis, upper epidermis (mid-rib)
"	Soapberry (*Shepherdia canadensis*)	aecia	lower epidermis
"	red current (*Ribes sp.*)	aecia	lower epidermis
Phragmidium sp.	raspberry (*Rubus idaeus*)	uredinia, telia	lower epidermis
"	rose (*Rosa acicularis*)	uredinia, telia	lower epidermis. petiole
Pucciniastraum sp.	birch (*Betula spp.*)	uredinia	lower epidermis
"	blueberry (*Vaccinium uliginosum*)	uredinia,	lower epidermis
"	Fireweed (*Epilobium spp.*)	uredinia, telia	lower epidermis
"	winter-green (*Pyrola spp.*)	uredinia	lower epidermis

VI. Discussion and conclusion

To date, at least five rusts differing in symptomology and spore morphology have been found on spruce trees in Alaska. Thus far, bud and fairbanks needle rust have been observed in the interior and tyonek needle rust has been found in south central Alaska. Witches' broom and cone rust infestations were found in both interior and south central, but witches' broom was more prominent on the spruces in the interior. The prevelence of cone rust seemed to be equal in both interior and south central; it has caused epidemics in both places.

Among these spruce rust diseases, cone and bud rust seem to have a long range impact on the regeneration and development of spruce forest. Cone rust has a devastating effect on seed production: (1) it causes retardation in the development of the embryo, (2) it seems to bind the seed to the cone and hinder its release. Rust mycelium has been observed on the surface of the seed coat, especially at the scale-side, which binds the infested seed so firmly to the scale that it is not released readily. However, the depth that these rust mycelia penetrate into the seed coat and their effect on the embryo development of the infested seed are unknown. These questions await further investigation.

The occurence of cone rust seems to fluctuate with cone production. 1977, for instance, was a very good cone production year in the Fairbanks vicinity; cone rust infestation in this area was also very prominent. 1978 was a poor cone producing year in the Fairbanks area; spruce cone rust was difficult to find. Similarly, the epidemic of cone rust found in the Tyonek State Forest also occured in an excellent cone producing year. While cone rust infestation is obviously limited by cone production, it is still not known how frequently cone rust epidemics coincide with good cone producing years and whether the infested area and severity also increase through the years.

Bud rust has been observed on spruce trees of all age classes, but it is most prominent on seedlings, causing severe stunting of the diseased shoots. Since bud rust affects primarily the current year's terminal bud, bud rust infestation could result in the loss of a year's increment in height. Thus far, no mortality of seedlings has been observed in association with bud rust disease. It is still unclear whether repeated infections would led to mortality. At present, besides its symptoms and behavior on the spruce and spore morphology, very little is known about aspects such as the alternate host, uredinia and telia stages, methods of spores dissemination and time and port of entry to the spruce.

Needle rust is a disease which could cause considerable damage to the growth of spruce trees; for it not only depletes the nutrients of spruce, diverting them to its own use, but it also causes needles to drop and further impairs the production of food in the tree. Whether there are degrees of tolerance of different age classes toward needle rust infestation is a question that remains to be answered.

The discovery of tyonek needle rust indicated that, at present, there are at least two rusts causing similar symptoms on spruce needles. How many other rusts also produce symptoms on spruce needles, and the manner of distribution and virulence of these rusts still require further investigation.

Witches' broom is the only rust that lives perennially on the spruce, notwith standing the localized nature of its infection. However, its long term parasitism on the host brings about a constant drain of host nutrient. How much does witches' broom affect the tree's growth? Does it affect the quality of the timber? Is it economically feasable to control the disease? These are important questions to answer in forest management.

Previously, cone rust(Chrysomyxa pyrolata), needle rust(C. ledicola) and witches' broom(C. arctostaphyli) have been reported to be the rust diseases found in Alaska(Anderson, 1952; Kimmey and Stevenson, 1957). With the discovery of bud rust and tyonek needle rust, a review of the taxonomical status of spruce rust found in Alaska as well as other Chrysomyxa rusts seems necessary. In the past, the taxonomy of spruce rust was based on light microscope abservation of spores. The surface structures of the aeciospores were generally described as varicose with the appendages on the spore surface labelled as warts. Characteristics of peridial cells were ignored or, it was suggested "absolutely no safe distinction could be found" (Savile, 1950). The scanning electron microscope studies conducted in this research revealed that both these "warts" of the spruce rust aeciospores and peridial cells possess unique features which were species specific and easily recognizable.

In Ziller's book "The Tree Rusts of Western Canada", one of the characteristics used to differentiate the genus of Chrysomyxa from other rusts based on spermogonia and aecia was that Chrysomyxa does not have smooth spot on aeciospore walls(1974). However, the SEM findings in this research are that both witches' broom and fairbanks needle rust have bands with somewhat rough surfaces, and smooth spots on tyonek needle rust were quite common.

In 1950 Savile's classic work "North American Species of Chrysomyxa", it is stated that

> "An important characteristic of the genus Chrysomyxa is the marked tendency for resemblence both of aeciospores to urediniospores of the same species and of ha bit in the alternate hosts.......................... .... This characteristic allows one to prognosticate with some confidence the appearance of undiscovered aecial stages or the relationship of unidentified ones"

This statement so far only found to be true in the fairbanks needle rust.

There is an uncanny resemblence between the aeciospores found on the spruce and the urediniospores found on labrador-tea. However, in the case of cone rust, the urediniospores found on the winter-green hardly resemble aeciospores at all.

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Jenifer Huang McBeath
January, 1979

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1. McBeath, J. H., 1978, "Scanning Electron and Light Microscopic Studies of Spruce Witches' Broom Rust Disease of Interior Alaska". Phytopathology News 12: 71. (abstract)

2. McBeath, J. H., 1978, "Scanning Electron and Light Microscopic Studies of White Spruce Needle Rust of Interior Alaska". Phytopathology News 12: 169. (abstract)

3. McBeath, J. H., 1978, "Scanning Electron and Light Microscopic Studies of white Spruce Cone Rust of Interior Alaska". Phytopathology News 12: 169. (abstract)

4. McBeath, J. H., 1979, "A New Bud Rust of Spruces in Interior Alaska" to be published in the Proceedings of IX International Congress of Plant Protection.

5. McBeath, J. H., 1979, "Scanning Electron and Light Microscopy of Spruce Bud Rust in Interior Alaska" Abstract to be published in the Proceedings of IX International Congress of Plant Protection.

6. ————————, "Witches Broom" Science Communities Forum, Sept. 1978

Publication in Preparation

1. "Bud Rust—A New Rust Disease of Spruce"

2. "Scanning Electron and Light Microscopy of Rust Diseases on Spruce; (1) Cone Rust.

3. "Scanning Electron and Light Microscopy of Rust Diseases on Spruce; (2) Needle Rust.

4. "Scanning Electron and Light Microscopy of Rust Diseases on Spruce; (3) Witches' Broom Rust.

5. "Scanning Electron and Light Microscopy of Rust Diseases on Spruce; (4) Bud Rust

6. "Scanning Electron and Light Microscopy of <u>Chrysomyxa</u> on Ledum.